

Beam Single Spin Asymmetries in SIDIS from an Unpolarized Proton

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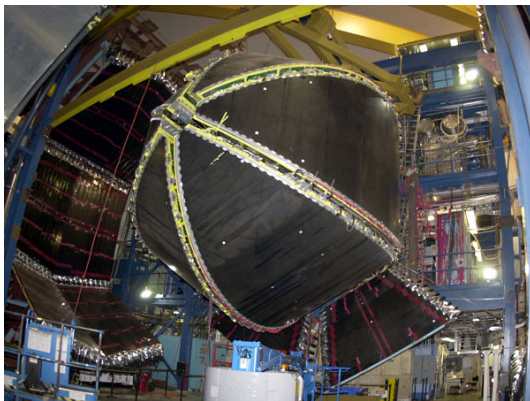
(for the CLAS Collaboration)

April 13, 2011



Introduction

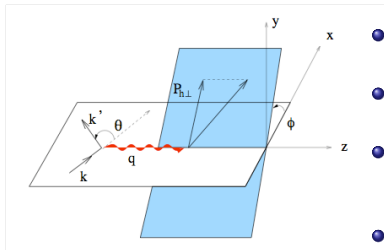
- We are measuring pion electroproduction in semi-inclusive deep inelastic scattering (SIDIS) using the CLAS detector at Jefferson Lab.
- Measuring the $\sin \phi$ moment ($A_{LU}^{\sin \phi}$) for all three pion channels in semi-inclusive reactions: $ep \rightarrow e\pi^{\pm,0}X$.



Semi-inclusive Deep Inelastic Scattering, $ep \rightarrow e\pi^{\pm,0}X$

$$d\sigma = d\sigma_0(1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos 2\phi} \cos 2\phi + \lambda_e A_{LU}^{\sin\phi} \sin\phi).$$

$$\lambda_e = \pm 1$$



- $W > 2 \text{ GeV}$ to stay above the resonance region
- $Q^2 > 1 \text{ GeV}^2$ to stay in the deep inelastic region
- $0.4 < z < 0.7$ to stay above the current fragmentation region and below the exclusive region
- $M_X > 1.2 \text{ GeV}$ to cut exclusive events

Theoretical Motivation for measurement of $A_{LU}^{\sin \phi}$

The $\sin \phi$ moment is a purely twist-3 object related to a structure function by:

$$A_{LU}^{\sin \phi} = \frac{F_{LU}^{\sin \phi}}{F_{UU,T}}, \text{ where } F_{UU,T} = C[f_1 D_1]$$

$$F_{LU}^{\sin \phi} = \sqrt{2\epsilon(1+\epsilon)} \frac{2M}{Q} C \left[-\frac{\hat{\mathbf{h}} \cdot \mathbf{k}_T}{M_h} (x e H_1^\perp + \frac{M_h}{M} f_1 \frac{\tilde{G}^\perp}{z}) + \frac{\hat{\mathbf{h}} \cdot \mathbf{p}_T}{M} (x g^\perp D_1 + \frac{M_h}{M} h_1^\perp \frac{\tilde{E}}{z}) \right]$$

- $e(x)$ is a twist-3 PDF and H_1^\perp is the naive time-reversal odd Collins fragmentation function which has previously been seen (at Belle, HERMES, and COMPASS) to exhibit opposite deflection of charged pions.
- g^\perp is the twist-3 T-odd distribution function. It may be easier to extract this function from A_{LU} of π^0 s because of flavor cancelation in the Collins function.
- \tilde{E} and \tilde{G}^\perp are twist-3 fragmentation functions.
- h_1^\perp is the leading-order TMD parton distribution, known as the Boer-Mulders function.

A. Bacchetta *et al.*, hep-ph/0611265v2, 2007

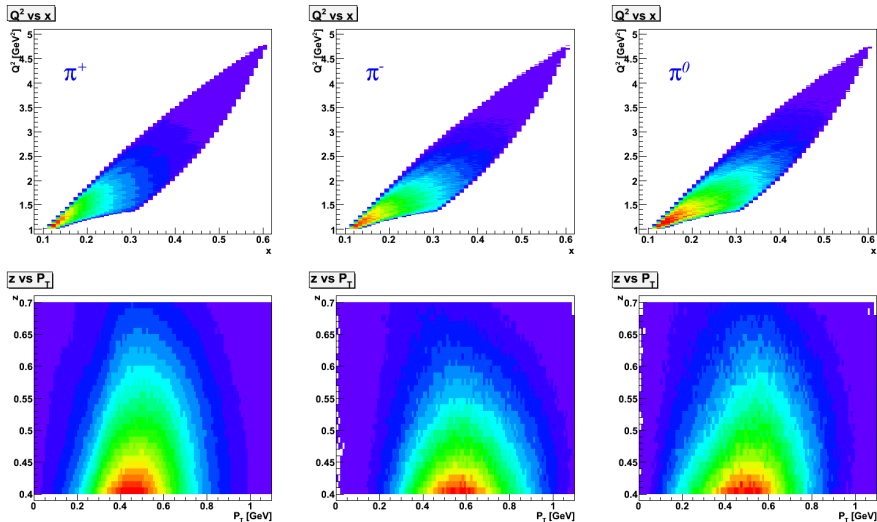
J.C Collins, Nucl. Phys. B396, 161 (1993), hep-ph/9208213

D. Boer, P.J. Mulders, Phys. Rev. D57 (1998) 5780, hep-ph/9711485

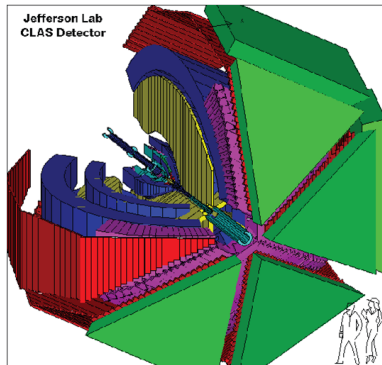
E1-f

- Data taken with CLAS detector during the E1-f run period between April and July of 2003.
- Used an unpolarized liquid hydrogen target.
- Torus magnet reduced to 60% of full current to maximize acceptance of charged pions.
- Longitudinally polarized electron beam with energy of 5.5 GeV and polarization of $75 \pm 3\%$.
- Integrated luminosity of 21 fb^{-1} .

Kinematic Coverage



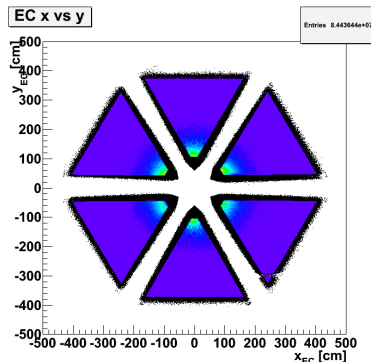
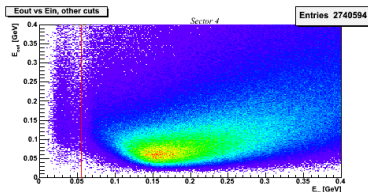
CLAS



- Electromagnetic Calorimeter (EC) is used for identification of electrons and photons.
- Cerenkov Counter (CC) is used in electron identification.
- Time-of-flight (TOF) is used in hadron identification.
- Drift chambers (DC) are used to measure momentum of charged tracks.
- Toroidal magnetic field is used to impart curvature to charged tracks.

Electron ID

- Electrons are identified by a series of ten cuts in the EC and CC of CLAS.
- The plot to the right shows the cut on the negative track position in the EC. The cut removed tracks hitting near the edges in each EC plan.
- The plot below shows a cut on the energy deposited in the EC. A cut is made to keep events with $E > 55$ MeV to separate electrons from π^- .



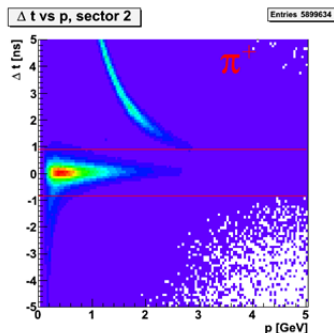
π^\pm ID

- A time-of-flight measurement is used to separate charged pions from other hadrons of like charge.
- The cut is $\pm 3\sigma$ from Gaussian fits to Δt in each sector.
- Δt is plotted against momentum to show the impact of the cut on other charged tracks.

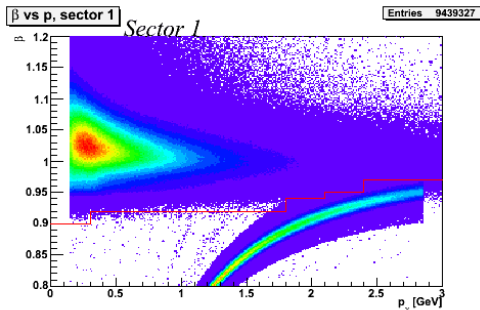
$$\Delta t = t_{meas} - t_{calc}$$

$$t_{calculated} = \frac{L\beta}{c}$$

$$\beta = \frac{\sqrt{p^2 + m_\pi^2}}{p}$$



Additional cuts are made for π^- to separate high energy electrons.

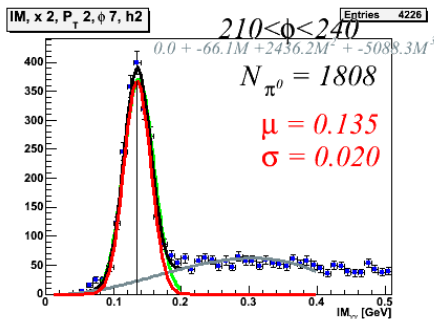


Photon ID Cuts:

- A geometric cut similar to that used for electrons is used in the EC.
- A cut is placed on $\theta_{e\gamma} > 12^\circ$.
- A cut is made on $E_\gamma > 0.15$ GeV.
- The β peak is fit in each momentum bin. The peak position and width stay constant with momentum, but the cut must be narrowed at high photon momentum to remove contamination from the neutron peak.

π^0 ID

The 2γ invariant mass is fit in each bin in x (5 bins), P_T (5 bins), and ϕ (12 bins) for each helicity state using a Gaussian + polynomial background. The parameters of the background fit were adjusted individually for each bin. The integrals of the Gaussian fits are used to calculate the number of π^0 s in each helicity state.



Systematic Uncertainty

Systematic errors are estimated by varying each analytic technique, and are found to be of similar magnitude as the measured statistical errors.

Method	Variation	π^+	π^-	π^0
Sampling Fraction Cut	2.0σ - 4.0σ	0.010	0.007	0.008
E_{inner} Cut	50-60 MeV	0.005	0.007	0.003
Electron Fiducial Cut	Tight, Medium, Loose	0.009	0.008	0.008
Pion Δt Cut	1.5σ - 4.0σ	0.011	0.009	NA
Pion Fiducial Cut	Loose, Medium, Tight	0.006	0.009	NA
Missing Mass	1.1-1.3 GeV	0.011	0.007	0.006
Fitting Function	$A \sin \phi, \frac{A \sin \phi}{1+B \cos \phi + C \cos 2\phi}$	0.003	0.003	0.003
Beam Polarization		0.0003	0.0003	0.0003
Background Subtraction	None, Function, Sideband	NA	NA	0.011
Background Asymmetry		NA	NA	0.007
Total Systematic Error		0.021	0.017	0.019
Average Statistical Error		0.006	0.014	0.011

BSA fits for π^+ P_T vs x

- $BSA = \frac{1}{P_e} \frac{N^+ - N^-}{N^+ + N^-}$

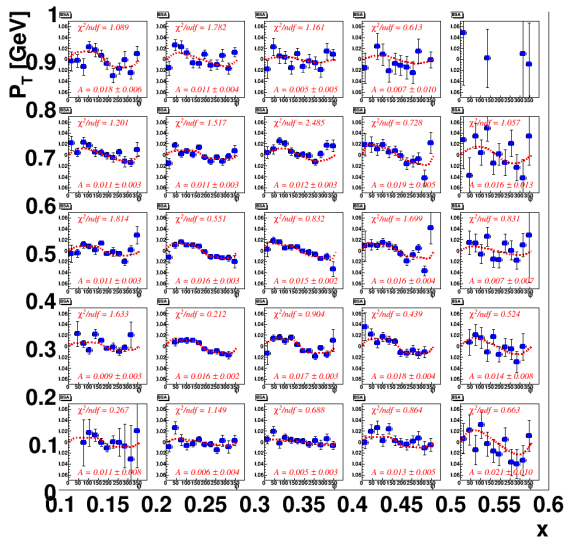
- Data is divided into five bins in x and five bins in P_T .

- Data is integrated over $0.4 < z < 0.7$

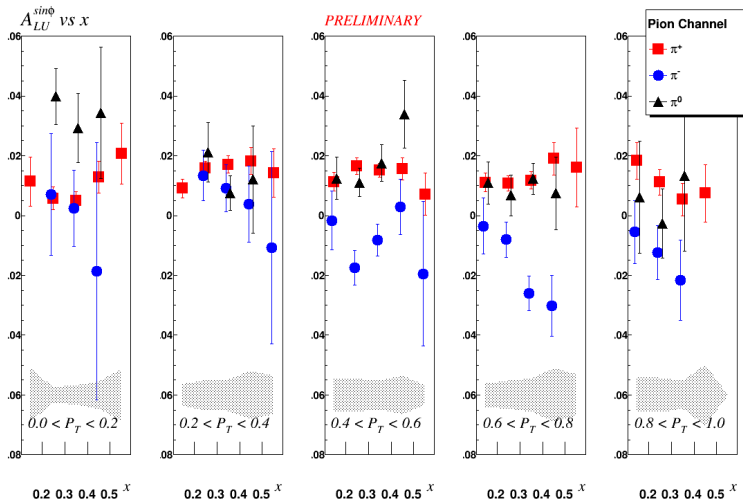
- Fit function:

$$\frac{A \sin \phi}{1 + B \cos \phi + C \cos 2\phi}$$

- Fits are performed in the same manner for other two pion channels.



2D Results



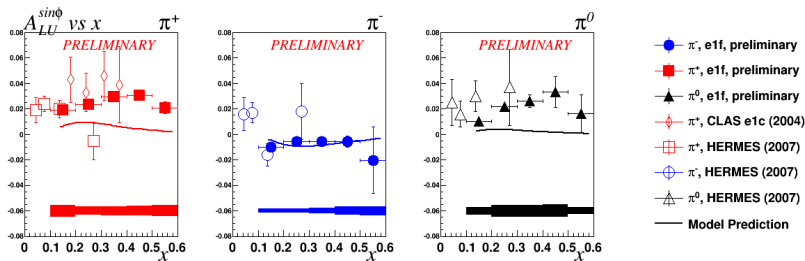
Systematic error band is drawn for π^+ .

Comparison to other data

To make the comparison the data is integrated over all P_T and $0.4 < z < 0.7$.

CLAS, H. Avakian et al., Phys.Rev.D69:112004,2004

HERMES, A. Airapetian et al., Phys. Lett. B648, 164 (2007), hep-ex/0612059



The model shown takes into account only the contribution to A_{LU} from $e(x) \otimes H_1^\perp$

P.Schweitzer, Phys.Rev. D67 (2003) 114010 [hep-ph/0303011]

Conclusion

- Preliminary results are shown for $A_{LU}^{\sin\phi}$ in all three pion channels.
- These results provide a significant kinematic extension and higher statistical precision than the previously published data.
- The results are of theoretical relevance for understanding quark-gluon-quark correlations in the nucleon.